Proposed Primary Pressure Standard Based on Capacitance Measurements

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Quantum mechanics and statistical mechanics can be used to calculate the pressure P of a sample of helium gas from the fundamental constants and measurements of the sample's thermodynamic temperature T and its dielectric constant ϵ . A "working equation" for the pressure can be obtained by eliminating the density ρ from the virial expansions for the pressure P and the dielectric polarizability, \emptyset i.e.

$$P = \rho RT(1 + B\rho + C\rho^2 + \dots)$$
 and $\Theta = \frac{\epsilon - 1}{\epsilon + 2} \frac{1}{\rho} = A_{\epsilon}(1 + b\rho + c\rho^2 + \dots)$.

Near 0° C, the uncertainty in determining the thermodynamic temperature of the sample will make a negligible contribution to ΔP , the uncertainty in calculating P. Most likely, ϵ would be measured with a stable cross capacitor with values in the range 0.5 pF to 1 pF. This small capacitance together with the small value $\epsilon - 1 \approx 7 \times 10^{-4}$ at 1 MPa and 0° C requires state-of-the-art capacitance measurements and their uncertainty will dominate ΔP . Assuming the fractional uncertainty in capacitance $\Delta C/C \approx 2 \times 10^{-9} (2 \text{ s.d.})$, we expect $\Delta P/P \approx 6$ ppm (2 s.d.) near 1 MPa and 0° C. That is, the expanded fractional uncertainty in the pressure with a coverage factor of two would be 6×10^{-6} . This pressure uncertainty near 1 MPa is smaller than that obtained in national standards laboratories; thus, such a helium sample could be used as a primary pressure standard near 1 MPa. It is essential to preserve the purity of the helium. For example, the mole fraction of water in the helium must be known to 10^{-8} because the molar polarizability of water is more than one hundred times that of helium. The deformation of the capacitor under hydrostatic pressure must be accounted for, perhaps with auxiliary measurements of its elastic constants. At pressures well below 1 MPa, $\Delta P/P$ will increase because $\epsilon - 1$ decreases with ρ while $\Delta C/C$ is unchanged. At pressures well above 1 MPa, $\Delta P/P$ will increase because of the uncertainties in C and C, the third density and dielectric virial coefficients.